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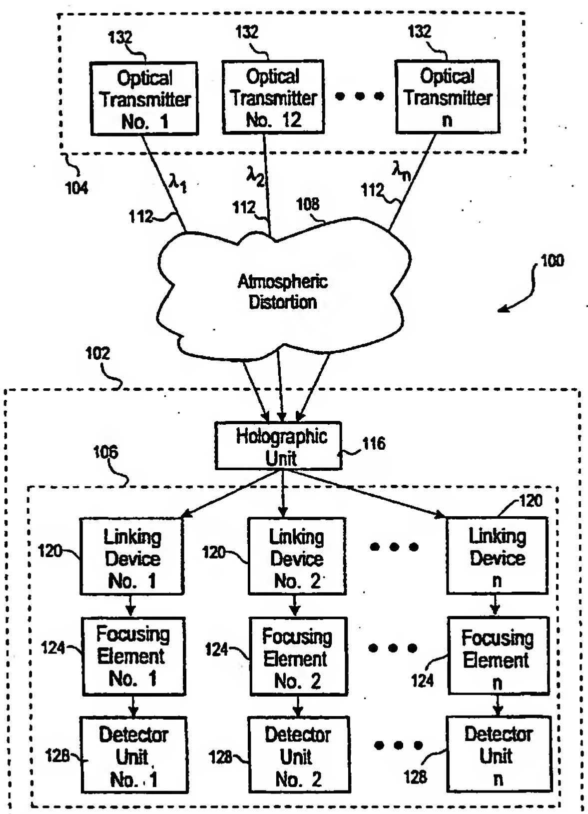
(54) Title: RECEIVING MULTIPLE WAVELENGTHS AT HIGH TRANSMISSION RATES



(57) Abstract: An apparatus for receiving data through the atmosphere at rates greater than 1 gigabit/sec. is provided. The apparatus includes a holographic unit and a detector assembly. The holographic unit receives light having different wavelengths representative of data at different frequencies. The holographic unit focuses the light on the detector assembly, preferably, a plurality of pick-off mirrors spaced from each other. Each pick-off mirror collects light at a predetermined wavelength. Each pick-off mirror directs the light at its associated wavelength to a very fast, high refractive index focusing lens. The detector assembly also includes a plurality of detector units. Each detector unit is in contact with one of the lenses. The detector units are able to receive tightly focused light having the transmitted data for subsequent processing.

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RECEIVING MULTIPLE WAVELENGTHS AT HIGH TRANSMISSION RATES

FIELD OF THE INVENTION

The present invention relates to laser communication receivers, and more specifically to an apparatus and method to receive high data rate signals transmitted through atmospheric distortion using a holographic unit.

BACKGROUND INFORMATION

Various communication systems are known for transmitting through the atmosphere. Most commonly, microwave communication devices are used for this communication. Additionally, various optical techniques for communication are known.

Microwave technologies used for data links through the atmosphere generally suffer from low data rates. For example, an 18 gigahertz (GHz) carrier is sometimes used to transmit between a satellite and a ground station. However, modulating 1 gigabit/sec. data rates on the 18 GHz carrier is not currently practically accomplished. By increasing the carrier frequency, the data rate may also be increased. For example, a 60 GHz carrier could support modulation data rates of 1 gigabit/sec. or higher. However, the atmosphere itself attenuates the 60 GHz carrier such that transmission through the atmosphere is not practical.

Terrestrial based optical transmission systems are known. However, these systems cannot transmit through the atmosphere at high data rates. These systems generally enable data to travel short distances between a ground-based transmitter and a ground-based receiver at very low data rates.

At present, large telescopes are used to allow optical transmission of data through the atmosphere. An optical carrier is modulated with data to transmit information through the atmosphere. Adaptive optics are used to focus the light to improve beam quality. These systems are large and expensive and can generally be operated for small intervals of time (e.g., 15 minutes). Additionally, these systems do not operate acceptably in daylight where sunlight can saturate the system.

SUMMARY OF THE INVENTION

In accordance with the present invention, apparatus and method for high-bandwidth data transmission through the atmosphere are disclosed. The apparatus includes a holographic unit and a detector assembly. The holographic unit receives light

Fig. 4 is a cross sectional view which schematically illustrates a parabolic volume hologram;

Fig. 5 is an enlarged cross sectional view which schematically illustrates a portion of a holographic mirror; and

Fig. 6 is a cross sectional view which schematically illustrates a parabolic volume hologram focusing incident laser light.

DETAILED DESCRIPTION

With reference to Fig. 1, an embodiment of a laser communication system 100 is shown in block diagram form. The laser communication system 100 includes a laser communication transmitter 104 and a laser communication receiver 102. Included in the communication receiver 102 is a holographic unit 116 and a detector assembly 106. The detector assembly 106 includes a linking device 120, focusing element 124 and a detector unit 128 for each modulated laser beam 112. In this embodiment, the transmitter 104 is located in a satellite and the receiver 102 is located in a ground station. However, other embodiments could put the transmitter in the atmosphere as well.

Atmospheric distortion 108 along the transmission path causes wavefront distortion in modulated laser beams 112. In other words, atmospheric distortion 108 from thermal currents or atmospheric turbulence bends the tightly focused laser light of the laser beams 112. As can be appreciated by those skilled in the art, atmospheric distortion 108 makes it difficult to focus the modulated laser beams 112.

Data is modulated onto a laser light carrier and is demodulated later from the laser light carrier in order to transport data great distances. In the laser communication transmitter, an optical transmitter 132 modulates data on a laser light carrier to form a modulated laser beam 112. The laser beam 112 is modulated with data at a rate greater than 1 gigabit/sec. and preferably, 2 gigabit/sec. In order for the laser beam 112 to reach the laser communication receiver 102, the beam 112 travels through atmospheric distortion 108. In the laser communication receiver 102, a holographic unit 116 focuses the laser beam 112 into a focus area on a linking device 120, such as a pick-off mirror. A single holographic unit 116 focuses each laser beam 112 on its respective linking device 120 which is positionally offset from the other linking devices 120. The linking device 120 redirects the laser beam 112 to a focusing element 124, such as a lens. After

for data rates above 1 gigabit/sec., currently available PIN diodes are limited to a diameter of approximately 40 microns.

The focusing element 124 receives the laser beam 112 from the linking device 120 and focuses the light to reduce the spot size diameter. This focusing reduces to less than 50 microns the greater than 100 micron spot size. Preferably, the spot size is reduced to 40 microns or less. Reducing the spot size allows focusing more light on the detector unit 128 which improves data transmission efficiency. For example, if a 40 micron detector were used with a spot size of 200 microns, only 4% of power would reach the detector.

To enable focusing, the speed of the laser light may be reduced in the focusing element 124 to 30% or less of the speed through free space. The focusing element 124 has an index of refraction of 2 or more. Preferably, the focusing element 124 could be made of Silicon or Germanium which respectively have indices of refraction of 3.5 and 4. Silicon is preferred for wavelengths around 1500 nm and Germanium is preferred for wavelengths around 2000 nm.

With reference to Fig. 2, a channel pick-off assembly or sorter block 200 is shown with four focal cones 204 incident thereon. Each focal cone 204 corresponds to a slightly different wavelength λ and has a focal area 208 offset from the focal areas 208 for the other wavelengths λ. The sorter block 200 includes a glass rod 212, four linking devices 120, four focusing elements 124, and four detector units 128. Each focal cone 204 corresponds to a different modulated laser beam 112 which carries different data. Although not shown in Fig. 2, the holographic unit 116 produces the four focal cones 204 which are spaced apart because each results from laser light of slightly different wavelengths λ. Each focal cone 204 has at its apex a focal area 208. In this embodiment, the focal cone is 20° to provide good separation between the four modulated laser beams 112.

The linking device, such as pick-off mirror 120, is positioned at the focal area 208 to redirect the laser light to a focusing element 124. The pick-off mirrors 120 are small to reduce the interference with other focal cones 204. The focusing element 124 focuses the laser light to reduce the spot size for a detector unit 128. Preferably, the detector unit 128 is in direct contact with the focusing element 124, although, it need not be.

The foregoing discussion of the invention has been presented for purposes of illustration and description. Further, the description is not intended to limit the invention to the form disclosed herein. Consequently, variations and modifications commensurate with the above teachings, within the skill and knowledge of the relevant art, are within the scope of the present invention. By way of example only, the invention need not be limited to a holographic mirror because a holographic lens could alternatively be used. The embodiments discussed hereinabove are further intended to explain the best mode known of practicing the inventions and to enable others skilled in the art to utilize the inventions in such, or in other embodiments and with the various modifications required by their particular application or uses of the inventions. It is intended that the appended claims be construed to include alternative embodiments to the extent permitted by the prior art.

9. A method, as claimed in Claim 1, wherein:

said detecting first data step includes reflecting said first data associated with said first wavelength by a first mirror to a focusing element and with an output of said focusing element being in communication with said first detector unit.

10. A method, as claimed in Claim 1, further including:

transmitting second data through the atmospheric distortion and with said second data that is being transmitted being associated with a second wavelength, different from said first wavelength, said transmitting second data step being conducted at a second rate of greater than one gigabit/second;

receiving said second data at a second position of said detector assembly; and

detecting said second data using a second detector unit.

11. A method, as claimed in Claim 10, wherein:

said detecting said second data step includes accepting said second data using a linking device, directing said second data to a second focusing element and with the output of said second focusing element being in communication with said second detector unit.

12. An apparatus for receiving high frequency data associated with a first wavelength, comprising:

a holographic unit that receives said data; and

a detector assembly responsive to said holographic unit for detecting said data, said detector assembly including a focusing element having a refractive index that reduces a focal spot size associated with said data.

13. An apparatus, as claimed in Claim 12, wherein:

said refractive index is greater than 2 and said focusing element reduces said focal spot size from a focal spot size diameter of greater than 100 microns to a focal spot size diameter of less than 50 microns.

14. An apparatus, as claimed in Claim 12, wherein:

said detector assembly includes a linking device and a detector unit and with said focusing element being disposed between said linking device and said detector unit, with said focusing element receiving an input from said linking device and providing an output to said detector unit.

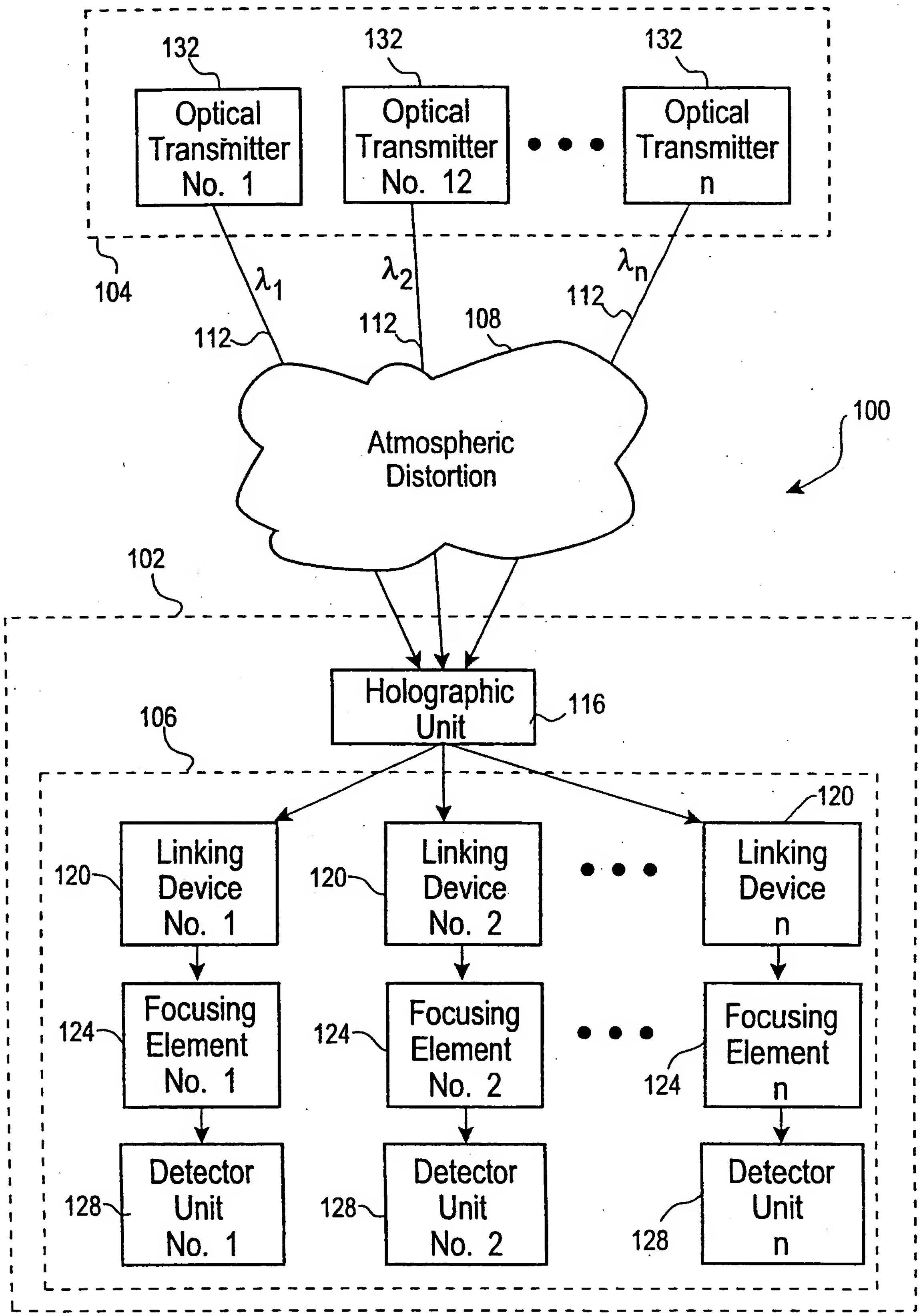
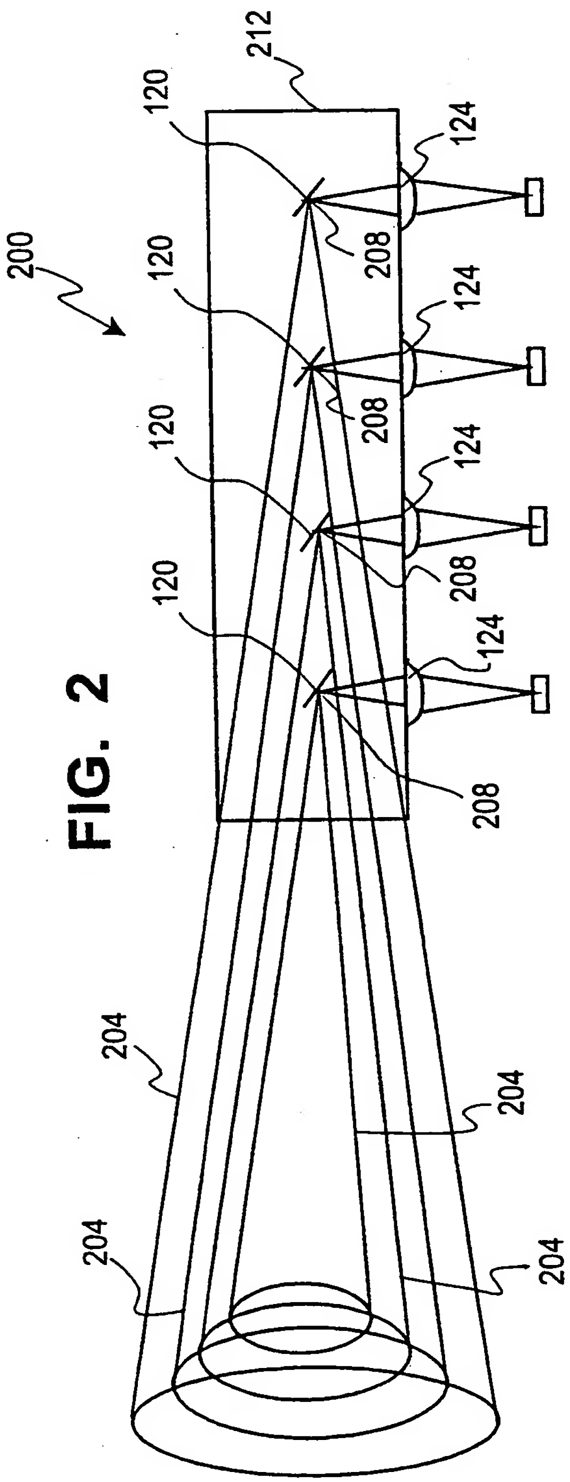

132
Optical Transmitter No. 1
132
Optical Transmitter No. 12
132
Optical Transmitter n
104
λ1
λ2
λn
112
112
112
108
Atmospheric Distortion
100
102
Holographic Unit
116
106
120
Linking Device No. 1
120
Linking Device No. 2
120
Linking Device n
124
Focusing Element No. 1
124
Focusing Element No. 2
124
Focusing Element n
128
Detector Unit No. 1
128
Detector Unit No. 2
128
Detector Unit n

FIG. 1


200
212
120
120
120
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124
124
124
124
208
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204

FIG. 2

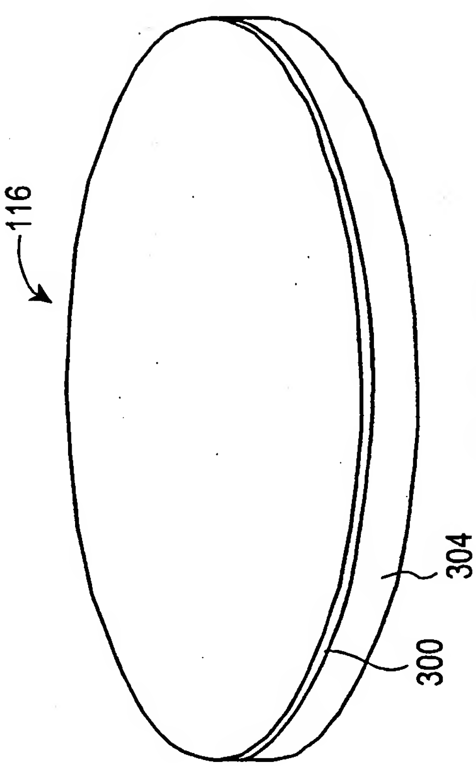
116
300
304

FIG. 3

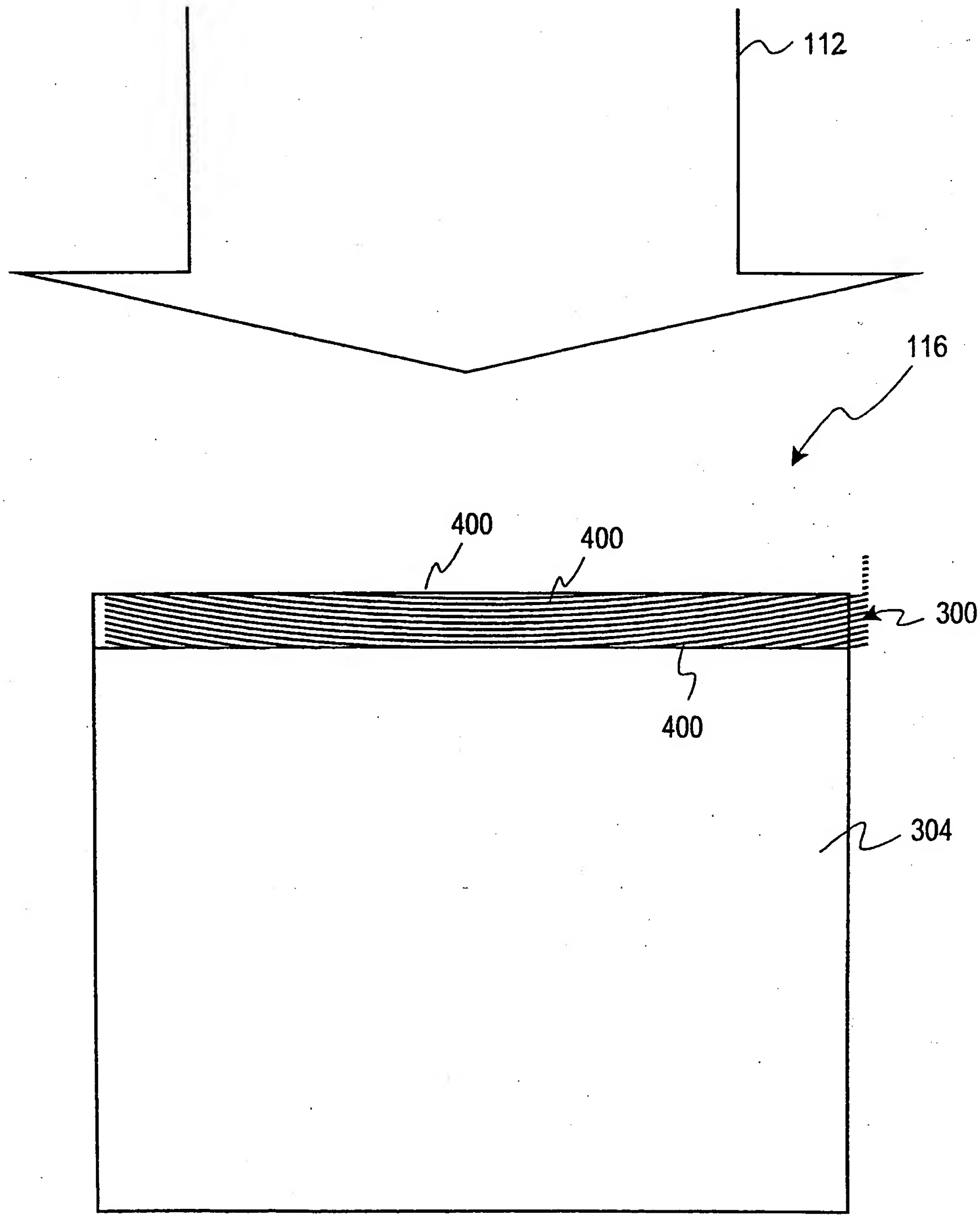

FIG. 4

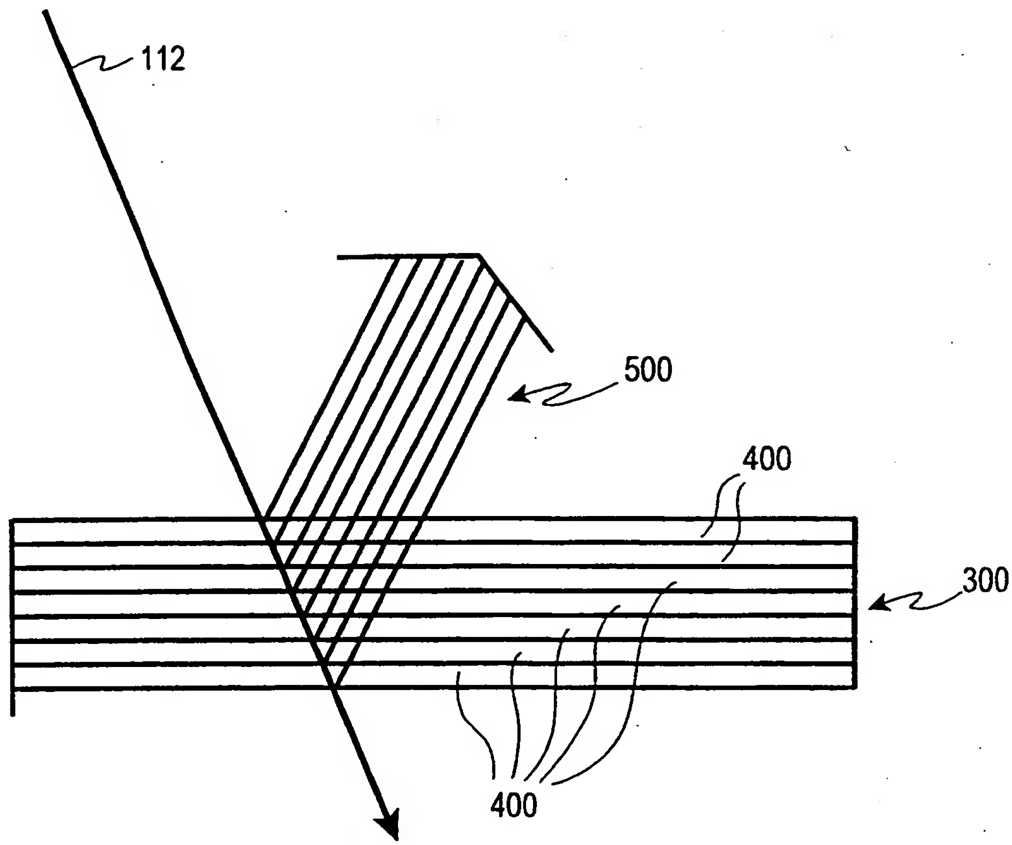

FIG. 5

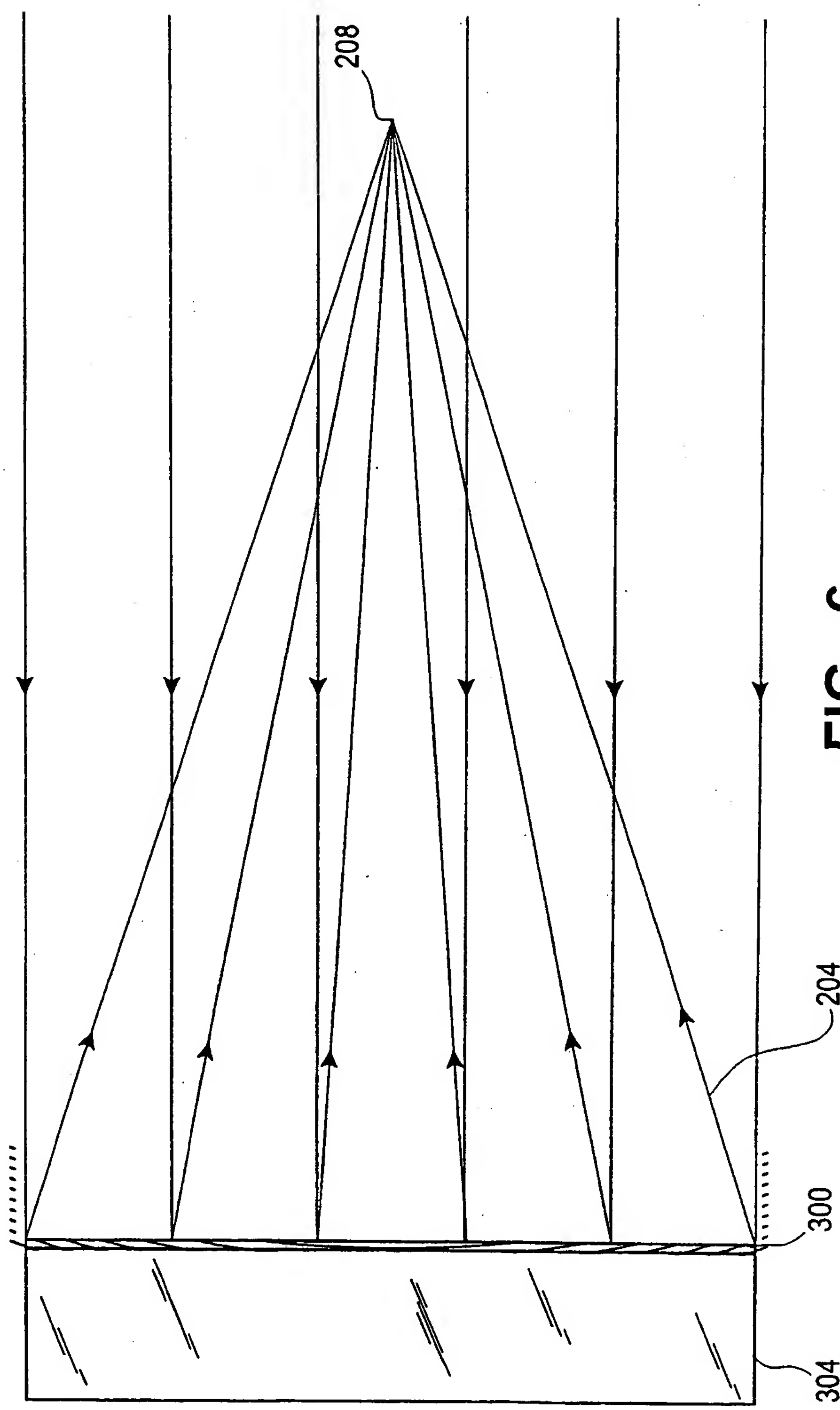

FIG. 6